

Incubator with food object detection based automatic heating process using internet of things technology

Heru Supriyono¹, Agus Supardi¹, Pramudya Kurnia², Mohammad Dwiki Aji Nugroho¹, Muhammad Satria Ananta¹, Helmi Hidayatullah¹

¹Department of Electrical Engineering, Faculty of Engineering, Universitas Muhammadiyah Surakarta, Surakarta, Indonesia

²Department of Nutritional Studies, Faculty of Health Science, Universitas Muhammadiyah Surakarta, Surakarta, Indonesia

Article Info

Article history:

Received Aug 30, 2025

Revised Feb 24, 2026

Accepted Mar 5, 2026

Keywords:

Food object detection

Incubator system

Smart oven

Telecontrol

Temperature control

ABSTRACT

Conventional incubators for heating food generally can be operated manually by both its temperature level and heating duration. This condition provides risk that the food will be heated inappropriately both at its temperature level and heating duration which in turn can decrease food quality. The objective of this article is to develop an incubator for heating food which is equipped with a food object detection based automatic heating process and using internet of things (IoT) technology for distance monitoring and control, which detects the type of food and heating it automatically at both temperature level and duration. The incubator was developed using components available in the market including GY-906-DCI sensor, OV5647 camera, Raspberry Pi 4, NodeMCU microcontroller, and Telegram bot. Testing results showed that the developed incubator system was able to detect food types in real-time, as well as automatically set temperature and incubation time parameters based on it. It was able to maintain a stable incubation temperature, with an average error of 2.74% and a temperature deviation of 1.23 °C. The developed incubator potentially improves safety and user convenience where the food is heated properly both at its temperature level and heating duration.

This is an open access article under the [CC BY-SA](https://creativecommons.org/licenses/by-sa/4.0/) license.



Corresponding Author:

Heru Supriyono

Department of Electrical Engineering, Faculty of Engineering, Universitas Muhammadiyah Surakarta

St. A. Yani Tromol Pos I Pabelan, Kartasura, Surakarta, Central Java, 57102, Indonesia

Email: Heru.Supriyono@ums.ac.id

1. INTRODUCTION

Temperature monitoring and control can be found in broad daily activities both in industries and domestic. In general, temperature control in various areas could be a heating or cooling process, for example temperature control for cooling an electric panel [1] and storing fresh food in [2]. An incubator is a common heating equipment that can be used in everyday life processes such as for hatching poultry eggs [3], [4], newly born baby care [5], biotechnology process [6], and so on. Food should be preserved in proper temperature and humidity both in the processing and in the storage phase in order to minimize germ and bacteria in the food as well as maintaining food quality variables [7]-[9]. The heating process for the food is able to prevent the growth of bacteria however too high temperature applied to the food will cause nutrition loss such as studied in [10]-[12] and similar research results.

Heating food is common practice in society in order to keep food still in a good condition and tasty. The temperature of the incubator or oven has to be designed properly so that it does not degrade the quality of the food. Specific food needs temperature level and heating duration in order to maintain its quality as reported by researchers for example for meat-based food [13], nuts [14], and other food types. The

temperature will affect the interaction of the food content such as protein, sugar, lipid and other components so that improper temperature applied to the food will affect or even to decrease the food quality [15], [16]. The higher temperature in the food processing the higher the probability of thermal damage of the food nutrition [17]. Besides temperature level, the heating duration also has to be considered because food may still be good quality when it is heated in high temperature but in very limited time [18].

Conventional incubators proposed by researchers for example in [19]-[22] were applying manual control which means that the temperature level and heating duration was only can be set directly to incubator manually. For ordinary people, this condition could be risky that the food will not be properly heated both its temperature level or duration which potentially can degrade the food quality as suggested in [23], [24]. An incubator which has an automatic heating mechanism based on food type will help ordinary people to heat food appropriately. The development of such incubators by researchers is still limited. This article proposes a general incubator or oven which has manual and automatic heating processes. It is equipped with a recommender system that uses a camera to detect food type and then determine the required temperature level and heating duration. The use of computer vision for food detection was also proposed in [25]. The developed incubator system is equipped with a voice stating the name of the detected food to assist users. Furthermore, the developed system has telemonitoring and telecontrol using internet of things (IoT) technology since it has been frequently incorporated in the monitoring and control for various applications such as proposed in [26]-[29] so that the controlled variables can be monitored and controlled remotely. The automated heating feature is potentially able to ensure the food to be heated properly at both its temperature level and heating period so that it can promote both safety and convenience for people.

2. METHOD

2.1. Proposed system

The developed food incubator system consists of three main parts namely input, process, and output, which are integrated with each other to produce automatic incubation with temperature and time settings based on visual object classification. Figure 1 shows the arrangement of these three main parts. In the input part there are three main components involving camera, temperature sensor, and push button. The OV5647 camera was chosen for capturing food images and sending them to the Raspberry Pi Zero 4 for classification using the vision-based object detection method. For temperature detection, the developed system used a non-contact temperature sensor of GY-906-DCI unlike the temperature sensor used in [30]. The GY-906-DCI sensor reads the food temperature in real-time. The use of a non-contact temperature sensor in the developed system facilitates healthier food processing compared to using contact temperature sensor in other researches for example used in [31]. The developed system is also equipped with push buttons which are used for manual control such as starting or stopping the process.

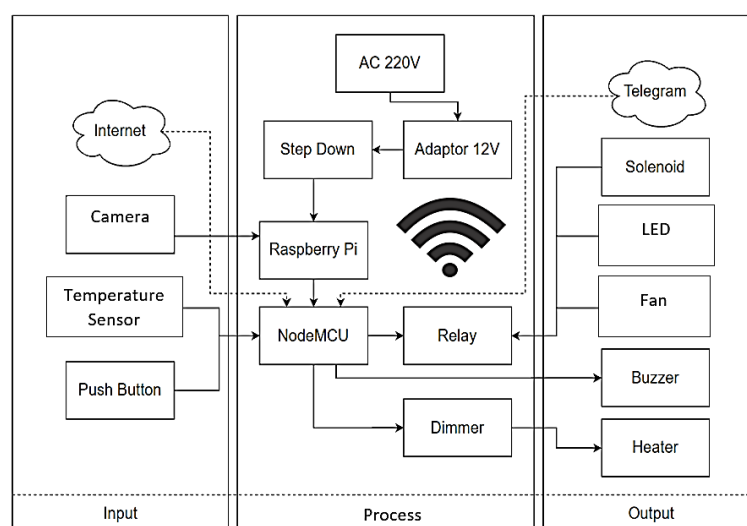


Figure 1. Block diagram representing general design of the developed incubator system

In the process part there are various main components including Raspberry Pi microcomputer, NodeMCU microcontroller, dimmer, relay, and power unit while the output part of the developed incubator

system consists of components including solenoid for lock the incubator door, light emitting diode (LED) as indicator, fan, buzzer, and heater. The Raspberry Pi Zero 4 microcomputer receives the data from the OV5647 camera and then computes them to detect the type of the food by applying classification computation. Raspberry Pi is a popular minicomputer which has been used for various applications such as in monitoring the temperature of a room [32]. The classification results of the Raspberry Pi Zero 4 then are sent to the NodeMCU ESP32 microcontroller via universal asynchronous receiver-transmitter (UART). Based on this data, the NodeMCU ESP32 microcontroller then give commands including: i) determines the target temperature and incubation time, ii) controls the positive temperature coefficient (PTC) air heater as the actuator via the AC light dimmer, iii) activates the 12 V DC fan, and iv) lock the door using solenoid lock for incubation room security.

The developed incubator system uses a 12 V DC power supply that is stepped down to 5 V via a step-down module. The NodeMCU ESP32 is connected to the internet via wireless data communication of 2.4 GHz with standard IEEE 802.11 by using wireless-fidelity (Wi-Fi) equipment, which allows sending and receiving data to and from the Telegram bot as a remote interface. Distance monitoring is a very important feature in modern applications since it can ease people to monitor something without coming to the location physically and it has been applied for various areas for example in electric power of home appliances control [33]. Wi-Fi is a popular data communication in the IoT application such as in [34], [35]. The use of Wi-Fi and internet for connectivity facilitating distance monitoring control with a much larger area compared to the use Bluetooth data communication proposed in [36]. Telegram bot provides real-time notifications covering food classification, temperature, remaining incubation time, and when the incubation process is completed. The system is also equipped with a buzzer as an alarm, a 20×4 liquid crystal display (LCD) to display temperature, time, and status offline.

2.2. Closed loop temperature control of the incubator

In general, the temperature control can be performed by using an open-loop control system such as proposed in [37] and closed control system. Closed loop control systems provide advantages including its stability and steady state error. The developed incubator system employs a closed-loop control for temperature control using proportional integral derivative (PID) control. Figure 2 shows the closed loop control principle of the developed incubator system.

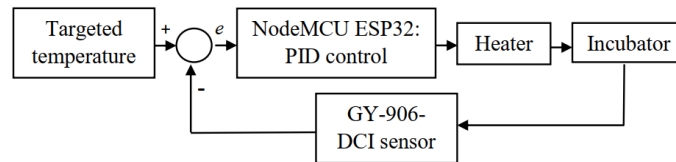


Figure 2. Closed loop temperature control using PID control applied in the developed system

The PID control used in the developed system has three main components namely the proportional constant (P), the integral constant (I), and the derivative constant (D). Each constant contributes to the speed, accuracy, and stability of the system's response to temperature changes. The PID control offers a simple control mechanism where the three PID variables can be set by using trial and error method without using advanced mathematical formulas. The PID control has satisfying performance in various application areas for example DC motor control in [38], industrial temperature monitoring of hot liquid tank [39], and temperature control of a fuel cell stack [40]. Mathematically, the PID control signal is formulated in (1), where $u(t)$ is a control signal (in the developed incubator system is the pulse width modulation (PWM) signal in the form of voltage sent to heater as the actuator, 0–100%), $e(t)$ is difference between the targeted and actual temperatures, K_p is the proportional constant, K_i is the integral constant, and K_d is the derivative constant.

$$u(t) = K_p e(t) + K_i \int_0^t e(t) dt + K_d \frac{de(t)}{dt} \quad (1)$$

This formula dynamically calculates the voltage level and in turn the power that must be supplied to the heater as the actuator based on the difference between the target temperature and the actual temperature. For example, in the initial condition when the temperature of the food object is still 27 °C and the target temperature is 40 °C, the difference value equal to 13 °C was used to calculate the control signal. With the predetermined PID constants of $K_p=2.5$, $K_i=0.2$, and $K_d=1.2$, the system produces a power output of

approximately 67.1%. This calculation allows the system to respond adaptively to temperature changes gradually and steadily, while minimizing errors (overshoot) in the heating process.

2.3. Hardware design

The electronic hardware circuit for the developed incubator system is depicted in Figure 3. The system circuit demonstrates the integration between the ESP32 as the main controller and the Raspberry Pi 4 as the image processor in the object detection phase. Four buttons (SELECT, UP, DOWN, and MODE) serve as manual feature selection control, with a 20×4 I2C LCD displaying the device status, and a buzzer as an alarm signal.

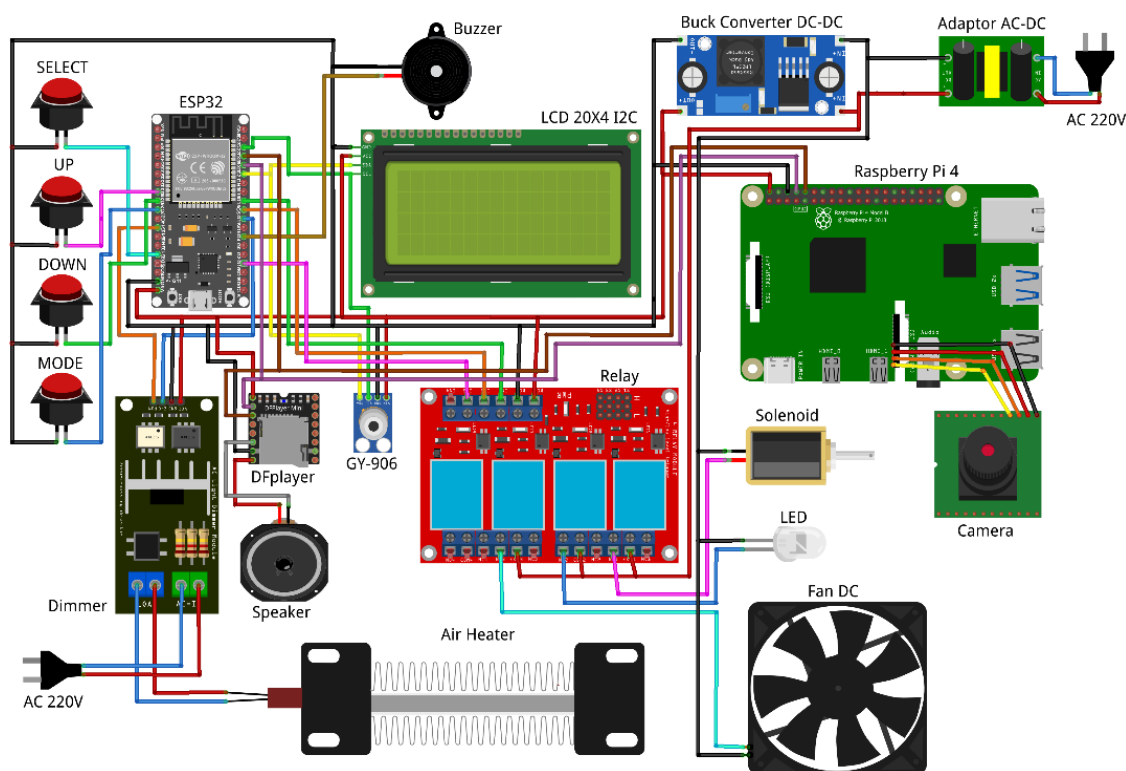


Figure 3. Wiring diagram of the hardware electronic circuit

The flow of electric current to the PTC air heater was controlled by using an AC light dimmer, with the heat intensity produced by the PTC air heater was gradually adjusted using a PWM signal of the NodeMCU ESP32 microcontroller which is determined by using the PID control value. Air circulation inside the incubator room distribution is assisted by a 12 V DC fan to ensure temperature level homogeneity across the room. LEDs serve as visual indicators and solenoid door lock is used for automatic locking. Sound notifications are provided by the DFPlayer Mini and a speaker. The main power source comes from a 12 V AC-DC adaptor, stepped down to 5 V with a buck converter for the ESP32 and Raspberry Pi 4, while the 220 V AC voltage is directly used by the heating element via a dimmer. In order to protect the heating process inside the cabin room, the incubator door is locked automatically by using a solenoid door lock when the heating process is started. The solenoid door lock is controlled via a relay for its safety. A 20×4 LCD displays temperature, time, and status. A buzzer is used as an end-of-process alarm. A 12 V LED for camera lighting so that the camera is able to perceive the heated food. A push button is used for manual control settings. All components are installed in a heat-insulated stainless steel incubation chamber. Component placement is adjusted to the shape and function of the device.

The developed incubator system was constructed based on a stove oven with a dimension of 29×35.5×34 cm. This oven was then modified to accommodate electronic hardware components without interfering with the heating function. Figure 4 shows the layout of the main components of the developed incubator system. An OV5647 camera and a GY-906-DCI sensor are installed inside the incubation chamber for food classification and temperature reading. The heating process is assisted by a heater and fan, with an automatic locking system using a solenoid door lock. The LCD, control buttons, and switches are located on

the front panel, while the component box and 12 V power supply are located at the bottom of the device to support the entire system.

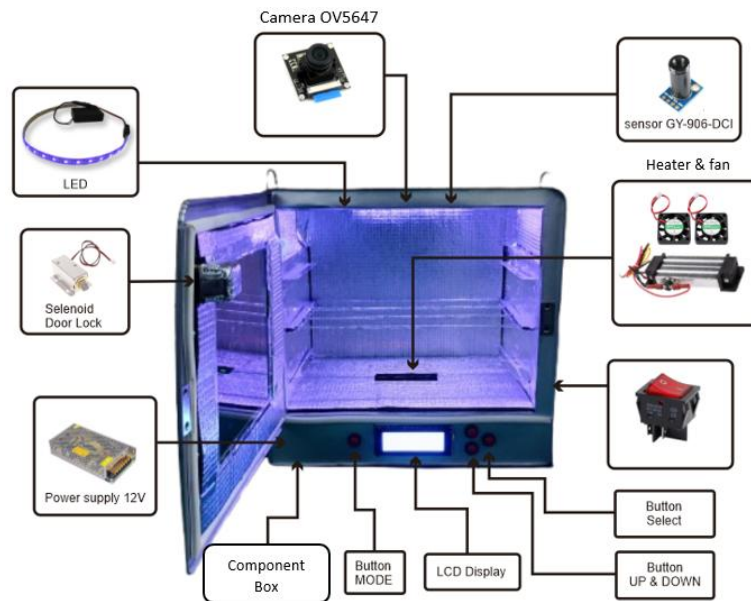


Figure 4. Positioning of the electronic hardware components of the developed incubator

2.4. Software design

The software of the developed incubator system consists of two main parts, namely the software of Raspberry Pi 4 as a visual food detection processing unit and the software of ESP32 microcontroller as the incubation system control center. The Raspberry Pi 4 is responsible for running food object detection based on a machine learning model that has been previously trained using the teachable machine algorithm, while the NodeMCU ESP32 regulates actuator control and monitoring of temperature and incubation time based on the classification results received from the Raspberry Pi via UART serial data communication. The NodeMCU ESP32 was programmed by using Arduino integrated development environment (IDE).

The remote monitoring and control user interface was implemented using the Telegram bot platform which was developed using the UniversalTelegramBot and WiFiClientSecure libraries on the NodeMCU ESP32 to connect the incubator to the Telegram bot while in Telegram mode. It allows users to access and control the developed incubator system in real-time via mobile devices. Telegram bot is an open application to be used for distance monitoring for example for lighting monitoring in [41]. After successfully connecting it to the Wi-Fi network, the NodeMCU ESP32 displays system status information via the LCD display and simultaneously begins listening/waiting for commands from the user via Telegram application.

On the NodeMCU ESP32 microcontroller side, the software was developed by using the Arduino IDE, a multipurpose software development environment which can be used not only for Arduino board families but also other boards such as board used in [42]. The program is divided into several classes according to their functions, making it more structured and modular. For example, the DeviceControl class is used to control the fan, buzzer, and solenoid; DisplayManager to manage the menu display on the LCD; TelegramHandler for communication with the Telegram bot; and TempController which implements the PID control algorithm to dynamically regulate the heating temperature based on the target temperature. The output of the PID control algorithm is converted into a control signal for the Robotdyn AC Dimmer module, which regulates the heating power through phase control.

The AUTO mode of the developed system allows automatic temperature and incubation time settings based on the food type classification results by the Raspberry Pi 4. Food detection is carried out in real-time using an OV5647 camera with you only look once (YOLO) algorithm and the OpenCV library which was then processed by using a food classification model in TensorFlow Lite (TFLite) format. YOLO and TFLite provide acceptable performance when applied in object detection such as proposed in [43], [44]. The general object detection computation step is as follows. First, for every food, samples of food photos were taken and stored in a database for the training phase. After the training is completed, the system is able

to recognize the food. In the detection process, Raspberry Pi 4 sends the detection results in the form of food names and confidence scores to the NodeMCU ESP32 via UART serial data communication in JavaScript object notation (JSON) format. Based on this data, the NodeMCU ESP32 sets the appropriate temperature and incubation duration value. The combination between the Raspberry Pi as a visual detection unit and the NodeMCU ESP32 as an actuator controller forms an efficient and adaptive incubation system according to food types.

2.5. System testing

System testing aims to evaluate the accuracy and reliability of the main components of the developed incubator system. There are two test phases namely calibration testing and all functional testing. Calibration testing is intended to determine the inaccuracy of the developed incubator system compared to a commercial instrument used by society. In the calibration testing, testing was conducted for the temperature measurement part using the GY-906-DCI temperature sensor, and the object detection part using the OV5647 camera. In the testing, the object detection using the OV5647 camera was tested by comparing its detection results to the original object to assess its image accuracy. Moreover, the temperature measurement results of the developed incubator using GY-906-DCI sensor was compared with the measurement results of a commercial instrument in the form of a thermogun device. The difference between these measurement values was calculated by using (2)-(4) which was then known as an inaccuracy where Δ is the difference value, A is the value read by the developed system, R is measurement value read by the commercial reading instrument, $\Delta(\%)$ is difference value in percent, $\Delta_{Average}(\%)$ is the average of difference in percent, $\sum \Delta(\%)$ is the sum of all difference value in percent for all test performed, and n is the number of test performed. The average difference value ($\Delta_{Average}(\%)$) in calibration testing for each part is used to evaluate the overall inaccuracy of the developed incubator system, the lower $\Delta_{Average}(\%)$ means the lower inaccuracy which shows the higher reliability.

$$\Delta = A - R \quad (2)$$

$$\Delta(\%) = \left(\frac{A - R}{R} \right) \times 100\% \quad (3)$$

$$\Delta_{Average}(\%) = \frac{\sum \Delta(\%)}{n} \quad (4)$$

3. RESULTS AND DISCUSSION

3.1. Bot Telegram interface display

The developed system used Telegram bot mobile phone application for inputting temperature control parameter which is facilitating remote controlling compared to using manual input using keyboard used in [45]. Figure 5 shows the sample of interface of the Telegram bot used in the developed incubator system (it was developed in *Bahasa Indonesia*) where Figure 5(a) shows Telegram bot interface display (was developed in *Bahasa Indonesia*) and Figure 5(b) shows feature for distance temperature and timer control manually. Telegram bot is used to monitor food temperature, incubation process status, and remotely control the system. Through commands such as start/stop, status, and settings, users can view information on the actual temperature, remaining incubation time, and heating power. Commands also allow users to manually set incubation parameters via the Telegram bot on their mobile phone without having to be present in person. The system will send an automatic notification when the incubation process is complete, making it easier for users to monitor and control in real time from anywhere.

The Telegram bot interface was configured with interactive buttons (custom keyboard) for choosing available menus involving status of the system, settings, heater control, and help. These menus allow users to monitor the temperature, set the temperature and timer, and activate or stop the heating process directly. Each command will be answered by the system by sending instant response information, including temperature status, heater power, and remaining time. After the /start command is sent, the user will see the main menu consisting of system status, settings, heater control, and help. The system status menu displays real-time information on the actual temperature, target temperature, heater power, and incubation time. When the process is complete, the system sends an automatic notification containing the final temperature of the food. Through the settings menu, users can change the target temperature and heating duration by responding to commands in a numeric format. Meanwhile, in the heater control menu, users can manually turn the heater on or off with a single click of a button.

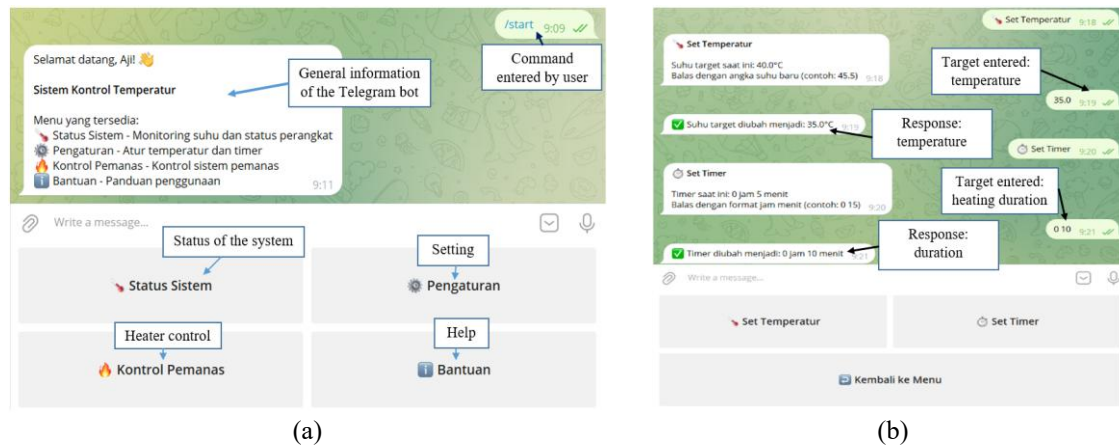


Figure 5. User interface view: (a) Telegram bot interface display and (b) controlling temperature and timer manually

3.2. Testing result

3.2.1. Calibration testing: food object detection

This test was conducted to assess the system's ability to recognize food types. In the test, the food is placed inside the incubator room, then a food detection process is started. The system should display the detection results, including the food name and confidence score, and then send the data to the ESP32 via UART serial data communication (the name of food is in *Bahasa Indonesia*). There are twelve types of food used in the test of the developed incubator system. Figure 6 shows the sample of food detection results of the developed incubator system: Figure 6(a) shows fried chicken detection and Figure 6(b) shows fried noodle detection. Table 1 summarizes food object classification testing results for all twelve foods.

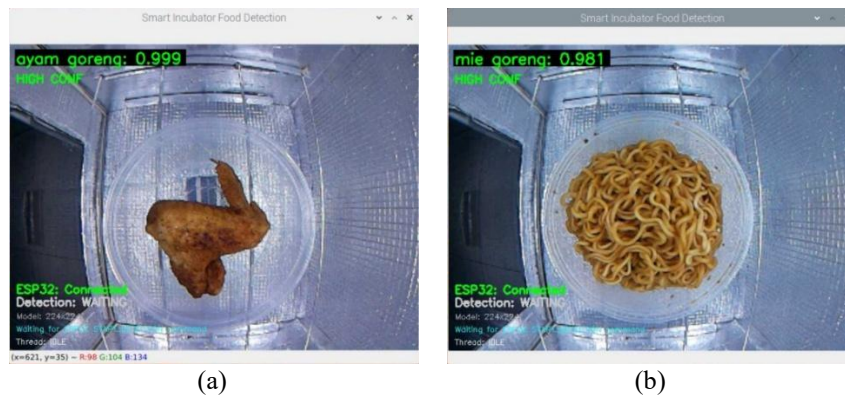


Figure 6. Display of the food detection results for fried chicken (the user interface is in *Bahasa Indonesia*): (a) fried chicken detection and (b) fried noodle detection

Table 1. Food object detection testing results

No.	Food object	Results sent to ESP32	Parameter setting	Response time (second)	Accuracy score (0-1)
1.	Fried chicken	Success	Success	9.16	0.988
2.	Floured fried chicken	Success	Success	8.92	0.957
3.	<i>Geprek</i> chicken	Success	Success	9.17	0.737
4.	Fried noodle	Success	Success	8.95	0.981
5.	Boiled noodle	Success	Success	8.91	0.824
6.	Spinach soup	Success	Success	8.95	0.773
7.	Tamarind vegetable soup	Success	Success	9.14	0.874
8.	Chicken soup	Success	Success	9.22	0.759
9.	Chicken <i>opor</i>	Success	Success	9.07	0.781
10.	Fresh milk	Success	Success	8.93	0.968
11.	Coffee	Success	Success	9.01	0.951
12.	Chocolate	Success	Success	9.20	0.829
Average				9.05	0.869

The test was performed for evaluating the system's speed and accuracy in classifying twelve food items. The experiment results in Table 1 showed that all objects were successfully recognized and their data was sent to the ESP32. The average response time was recorded at 9.05 seconds, with a narrow range of 8.93–9.22 seconds, indicating stable system performance. The highest accuracy was achieved by "Fried chicken" (0.983), while the lowest was achieved by "Greek chicken" (0.737), with an average accuracy score of 0.869. These results indicate the system is reliable enough for automatic detection in the food incubation process.

3.2.2. Calibration testing: temperature measurement testing

This test was performed to measure the inaccuracy of the temperature measurement based on the GY-906-DCI temperature sensor in reading food surface temperatures. The test was conducted by performing a heating process and then comparing the readings of the developed incubator system to that of a commercial instrument and then the difference values were calculated by using (2)-(4). The test was conducted ten times. Table 2 summarizes the calibration testing results for temperature measurement. The results showed that the average difference between the sensor and reference device values was 1.05 °C, with an average error value of 2.28%. The highest error was recorded at 4.35% and the lowest at 0.72%, which is still within the tolerance limits of non-contact temperature measurements for monitoring purposes. It can be seen that it reflects the consistency and accuracy of the sensor readings. These results strengthen the claim that the GY-906-DCI is able to provide reliable temperature data under actual operational conditions. With this performance, this sensor is suitable for use as a temperature monitoring component in an IoT-based automatic incubation system.

Table 2. Calibration testing results of temperature measurement: commercial instrument vs GY-906-DCI-based developed system

No.	Commercial instrument (°C)	Developed system (°C)	Δ (°C)	Δ (%)
1.	36.8	38.4	1.6	4.35
2.	38.2	39.8	1.6	4.19
3.	41.6	41.9	0.3	0.72
4.	43.1	43.5	0.4	0.93
5.	45.6	45.1	0.5	1.10
6.	47.8	47	0.8	1.67
7.	50.5	49.4	1.1	2.18
8.	52.5	51.1	1.4	2.67
9.	55.4	53.1	2.3	4.15
10.	56.1	55.6	0.5	0.89
Average			1.05	2.28

3.2.3. Testing of solenoid door lock actuators, fans, and liquid crystal displays

This test was conducted to ensure that the solenoid door lock actuator, DC fan, and LED can operate according to commands from the ESP32 microcontroller and to evaluate the actuator's response speed to system commands when the incubation process begins and ends. The solenoid is tested by commanding the system to lock and unlock the incubation chamber door. The DC fan is tested by automatically activating air circulation during the incubation process. The LED was tested as a visual indicator that shows system status, such as active or completed processes. Every command sent via the Telegram bot or manual button was observed to ensure the actuator responds as intended. Table 3 shows the testing results for actuators. The results suggested that all actuators (solenoid, fan, and LED) were successfully turned on when the process began and then turned off again when the incubation process ended. Response times were recorded as quite fast and consistent, with the solenoid having the fastest time at 0.6 seconds, while the fan and LED each had a response time of 0.82 seconds. The overall average response time was 0.75 seconds. This demonstrates that the system is capable of providing real-time and responsive actuator control, which is important for maintaining the stability of the heating process and the safety of the equipment.

Table 3. Solenoid, fan, and LED testing results

No.	Actuator	Start heating	End heating	Response time (s)
1.	Solenoid	On	Off	0.6
2.	Fan	On	Off	0.82
3.	LED	On	Off	0.82
Average (s)				0.75

3.2.4. DFPlayer mini module testing

The test was conducted to ensure the DFPlayer Mini module could play audio pronunciations of food names, as an audio notification upon successful food object classification. The DFPlayer module was controlled by a NodeMCU ESP32 microcontroller via serial communication using pre-programmed commands. Testing was conducted by sending audio file playback commands through both automatic and manual scenarios. System response was observed to ensure the DFPlayer could read files from the microSD card and produce audio output through the speaker. Table 4 presents the test results of the voice feature in naming food detected by the developed incubator. It can be noted from the test results that all audio files played correctly and output sound smoothly. Response times range from 5.25 to 6.15 seconds, with an average of 5.90 seconds, indicating an acceptable lag time for the system's audio notification requirements. File compatibility and sound playback reliability support this feature.

Table 4. Voice feature for recognizing food using Dfplayer Mini testing result

No.	Food	Prepared audio file	Played audio file	Voice out	Response time (s)
1.	Fried chicken	001.mp3	Correct	Correct	6.03
2.	Floured fried chicken	002.mp3	Correct	Correct	5.96
3.	<i>Geprek</i> chicken	003.mp3	Correct	Correct	5.25
4.	Fried noodle	004.mp3	Correct	Correct	6.10
5.	Boiled noodle	005.mp3	Correct	Correct	6.06
6.	Spinach soup	006.mp3	Correct	Correct	5.43
7.	Tamarind vegetable soup	007.mp3	Correct	Correct	6.15
8.	Chicken soup	008.mp3	Correct	Correct	5.86
9.	Chicken opor	009.mp3	Correct	Correct	5.75
10.	Fresh milk	010.mp3	Correct	Correct	5.98
11.	Coffee	011.mp3	Correct	Correct	6.13
12.	Chocolate	012.mp3	Correct	Correct	6.09
Average (s)					5.90

3.2.5. Telegram bot testing

Testing was conducted to ensure that the Telegram bot functioning well as a remote communication interface between the user and the system. The primary focus of the testing was the system's response to various commands. Each command was tested by observing the system's response, including response speed, accuracy of displayed information, and successful execution. Automated notifications, such as final temperature information or process completion, were also tested to ensure they were delivered in a timely manner and that the message content reflected actual conditions. Table 5 outlines the test results of the Telegram bot feature of the developed incubator. The test results showed that every command sent by users via Telegram was successfully processed by the developed system, from viewing status and setting parameters to controlling the incubation process. The average system response time to commands was 1.80 seconds, with the fastest response occurring for the "Set Temperature" command (1.1 seconds) and the slowest for the "Return to Menu" command (2.84 seconds). Despite variations in response times, the overall system demonstrated responsive and reliable performance for IoT-based control.

Table 5. Telegram bot testing results

No.	Command given (in Bahasa Indonesia)	Main function	System response	Response time (s)
1.	<i>Status Sistem</i> (System status)	To view the current status of the incubator system	Displays temperature, heating power, and timer data	1.5
2.	<i>Kontrol Pemanas</i> (Heater control)	To enter the heater start/stop menu	Displays the heater start/stop menu	2.46
3.	<i>Mulai Pemanas</i> (turn on the heater)	To give the command to start the incubation process	The incubator begins the incubation process	2.57
4.	<i>Hentikan Pemanas</i> (turn off the heater)	To give the command to stop the incubation process	The incubator stops the incubation process	1.42
5.	<i>Kembali ke Menu</i> (back to the menu)	To return to the main menu	Displaying the main menu	2.84
6.	<i>Pengaturan</i> (Setting)	To enter the set temperature and set timer menu	Displays the set temperature and set timer menus	1.5
7.	<i>Set Temperatur</i> (Temperature setting)	To set the target temperature	The system changes the target temperature according to the input	1.1
8.	<i>Set Timer</i> (timer setting)	To set the incubation timer	The system changes the incubation timer according to the input	1.2
9.	<i>Bantuan</i> (help)	To display the usage guide	Displays the usage guide	1.59
Average (s)				1.80

3.2.6. Automatic temperature control testing

Maintaining temperature stability is crucial for maintaining nutritional value. For example, vitamin C in vegetables begins to degrade significantly at temperatures above 70 °C (losing >50% at 80 °C) [46]. The automatic temperature control test was conducted to evaluate the developed incubator system's performance in automatically regulating the incubation room temperature using a PID control method. Testing was conducted to assess the system's effectiveness in maintaining temperature stability during the automated incubation process. The test was conducted by running the incubation process and then monitoring temperature changes periodically until the incubation process was complete. The target temperature was set at 45 °C, and monitoring was performed periodically every two minutes for 18 minutes. Table 6 summarizes the automatic temperature control testing results. It can be seen that at the 2nd minute, the food temperature was still quite far from the target (40.1 °C), with a difference of 4.9 °C and an error of 10.89%. However, the PID-controlled system was able to progressively reduce the difference until it approached the target temperature at the 8th minute. After the 10th minute, the temperature stabilized at around 45.5 °C with an average difference of only 0.5–0.6 °C or equal to from 1.11–1.33%. The overall average temperature difference was 1.23 °C or equal to 2.74%, indicating the system's performance was acceptably accurate and responsive in adjusting the temperature as needed.

Table 6. Automatic temperature control testing results

No.	i-th minute	Actual temperature (°C)	Targeted temperature (°C)	Δ (°C)	Δ (%)
1.	2	40.1	45	4.9	10.89
2.	4	42.3	45	2.7	6.00
3.	6	44.1	45	0.9	2.00
4.	8	45.1	45	0.1	0.22
5.	10	45.4	45	0.4	0.89
6.	12	45.5	45	0.5	1.11
7.	14	45.5	45	0.5	1.11
8.	16	45.6	45	0.6	1.33
9.	18	45.5	45	0.5	1.11
		Average		1.23	2.74

3.3. Discussion

Functionally, the application of the IoT in the developed incubator almost similar to other applications for example incubator for mushroom cultivation [47] and water quality monitoring [48]. Since the system was developed by using hardware and software available in the market or open source, the main difference is in its design, features, hardware components, and software. It was reported that the use of IoT technology in monitoring and control can potentially improving energy efficiency [49], [50]. Table 7 shows the comparison of the developed incubator system to other published works.

Table 7. Comparison of the developed system to other previous works

No.	Authors	Temperature sensor	Processor	Distance monitoring feature	Distance control feature	Object-based automatic temperature control
1.	The developed system	GY-906-DCI	ESP32 and Raspberry Pi 4	Telegram bot	Yes, Telegram bot	Yes, camera-based food or drink object detection
2.	[19]	DS18B20	NodeMCU ESP8266	Blynk platform	No	No
3.	[20]	SMT172	32-bit Cortex-M3 MCU	No	No	No
4.	[21]	Si7020-A20 and DHT22	Raspberry Pi 4	No	No	No
5.	[22]	LM 35	ARDUINO UNO	No	No	No
6.	[51]	DHT11	ESP32	Blynk platform	No	No
7.	[52]	DHT22	ESP32	Web and mobile application	No	No
8.	[53]	SHTC3	Arduino Nano	No	No	No
9.	[54]	DS18B20 and DHT11	NodeMCU 8266	Web	Web	No

Compared to conventional incubator, the developed incubator system is potentially able to improve safety in which it can help users minimizing over heating for food which can decrease quality of the food as well as user convenience where users just put the food inside the incubator and then press the ON button without need to manually determine the proper temperature and heating duration. The adoption of IoT technology for monitoring and control of the developed incubator system provides an advantage compared to conventional incubators in which it enables users to operate the incubator from a distance. It can be seen from the table that the developed incubator system has unique features namely it has two heating types namely manual and object detection based automatic heating process while other proposed systems have

Incubator with food object detection based automatic heating process using internet ... (Heru Supriyono)

manual heating systems only. Further, from the component choosing, the developed system uses a different temperature sensor and Telegram bot to other proposed works. This developed system can be enhanced by employing adaptive PID control like proposed in [55], [56], adding artificial intelligence (AI) in the temperature control like proposed in [57]-[59] or combination of PID control and AI such as proposed in [60]. The further development of the system in accordance with the industrial standard is also needed. Besides for temperature control, more AI algorithms and models also can be applied for food object detection to result in more accurate detection.

4. CONCLUSION

An incubator for general heating purposes with its unique automatic heating control and distance monitoring features using IoT technology has been successfully developed. The functional test results showed that the developed incubator worked stably as expected both in manual and automatic heating mechanism as well as its distance control and measurement features. The calibration testing results showed that the developed system has closed measurement results with acceptable measurement differences compared to the measurement results by using a commercial measuring instrument. Testing results of the heating process for actual food types showed that the developed system was able to detect the food type correctly and determine its temperature level and heating duration automatically as expected. This will facilitate ordinary people to heat the food properly without degrading its quality. The limitation of the developed incubator system is that it was designed for small capacity and tested for twelve food types only. The developed incubator can be enhanced by applying more advanced temperature control and more intelligent algorithms for object detection, adding more data sets of food types, and increasing its size and capacity. Furthermore, the developed incubator should be improved in accordance with the industrial standard.

ACKNOWLEDGMENTS

Authors thank to *Direktorat Riset, Teknologi, dan Pengabdian Kepada Masyarakat (DRTPM)*, *Kemendikbud* Republic of Indonesia for providing research support.

FUNDING INFORMATION

This research was funded by *Direktorat Riset, Teknologi, dan Pengabdian Kepada Masyarakat (DRTPM)*, *Kemendikbud* Republic of Indonesia with the scheme of *Penelitian Fundamental Reguler* year 2024 with decree number 0459/E5/PG.02.00/2024 and contract number 007/LL6/PB/AL.04/2024, 196.22/A.3-III/LRI/VI/2024.

AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Heru Supriyono	✓	✓			✓		✓		✓	✓		✓		✓
Agus Supardi		✓		✓	✓		✓		✓	✓		✓		✓
Pramudya Kurnia		✓			✓	✓	✓			✓				✓
Mohammad Dwiki Aji Nugroho		✓	✓			✓		✓	✓		✓			
Muhammad Satria						✓		✓	✓				✓	
Ananta														
Helmi Hidayatullah			✓			✓			✓		✓		✓	

C : Conceptualization

M : Methodology

So : Software

Va : Validation

Fo : Formal analysis

I : Investigation

R : Resources

D : Data Curation

O : Writing - Original Draft

E : Writing - Review & Editing

Vi : Visualization

Su : Supervision

P : Project administration

Fu : Funding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

Data availability is not applicable to this paper as no new data were created or analyzed in this study.

REFERENCES

- [1] P. O. Mbamaluikem, H. S. Okeke, and E. O. Fagbuaro, "An automatic temperature monitoring and control system for electric power distribution panel," *International Journal of Trend in Scientific Research and Development (IJTSRD)*, vol. 6, no. 7, pp. 778-782, 2022.
- [2] A. Saquet, J. Streif, and D. Almeida, "Experimental device to study temperature effects on food quality: development and application," *Technology in Horticulture*, vol. 4, pp. 1-6, 2024, doi: 10.48130/tihort-0024-0004.
- [3] S. Purwanti, A. Febriani, M. Mardeni, and Y. Irawan, "Temperature monitoring system for egg incubators using Raspberry Pi3 based on Internet of Things (IoT)," *Journal of Robotics and Control (JRC)*, vol. 2, no. 5, pp. 349-352, 2021, doi: 10.18196/jrc.25105.
- [4] R. Wahyuni, Y. Irawan, A. Febriani, N. Nurhadi, H. T. Saputra, and R. Andrianto, "Smart egg incubator based on IoT and AI technology for modern poultry farming," *Computer Science ILKOM*, vol. 16, no. 2, pp. 134-144, 2024, doi: 10.33096/ilkom.v16i2.1957.134-144.
- [5] N. F. Hidayati, E. Yulianto, and A. Kholiq, "Baby incubator using PID control based on Kangaroo mode (Kangaroo mode and humidity)," *Journal of Electronics, Electromedical, and Medical Informatics (JEEEMI)*, vol. 1, no. 2, pp. 13-17, 2019, doi: 10.35882/jeeemi.v1i2.3.
- [6] M. Kumar, D. Prasad, B. S. Giri, and R. S. Singh, "Temperature control of fermentation bioreactor for ethanol production using IMC-PID controller," *Biotechnology Reports*, vol. 22, pp. 1-10, 2019, doi: 10.1016/j.btre.2019.e00319.
- [7] W. P. van der Vossen-Wijmenga, H. M.W. den Besten, and M. H. Zwietering, "Temperature status of domestic refrigerators and its effect on the risk of listeriosis from ready-to-eat (RTE) cooked meat products," *International Journal of Food Microbiology*, vol. 413 (2024), 110516, pp. 1-14, 2024, doi: 10.1016/j.ijfoodmicro.2023.110516.
- [8] O. S. Nanje, V.-T. Z. S. Ninying, F. T. Djikeng, T. A. Morfor, and A. U. Achidi, "Effect of different reheating processes and conditions on the nutritional, functional, and microbiological properties of cow meat," *Food Science & Nutrition*, vol. 12, pp. 4233-4247, 2024, doi: 10.1002/fsn3.4083.
- [9] N. M. L. Malak and N. S. M. Soliman, "The effect of time and temperature variations on the microbial load and deterioration criteria of leftover cheeseburger sandwiches," *Advances in Animal and Veterinary Sciences*, vol. 9, no. 11, pp. 1925-1932, 2021, doi: 10.17582/journal.aavs/2021/9.11.1925.1932.
- [10] W. Warkoyo and O. P. Pakpahan, "Effect of processing temperature on meatballs under dynamic storage condition using evaluation of the Arrhenius model," *Journal of Agricultural Science and Technology*, vol. 25, no. 2, pp. 379-390, 2023, doi: 10.52547/jast.25.2.379.
- [11] D. Kmiecik, M. Fedko, J. Małacka, A. Siger, and P. L. Kowalczewski, "Effect of heating temperature of high-quality Arbequina, Picual, Manzanilla and Cornicabra olive oils on changes in nutritional indices of Lipid, Tocopherol content and Triacylglycerol Polymerization process," *Molecules*, vol. 28, pp. 1-19, 2023, doi: 10.3390/molecules28104247.
- [12] S.-J. Mun *et al.*, "Effects of cooking methods and temperatures on quality and safety of dried red peppers (*Capsicum annuum* L.)," *LWT - Food Science and Technology*, vol. 191, pp. 1-8, 2024, doi: 10.1016/j.lwt.2023.115588.
- [13] E. Hasani, B. Csehi, L. Darnay, M. Ladányi, I. Dalmadi, and G. Kenesei, "Effect of combination of time and temperature on quality characteristics of sous vide chicken breast," *Foods*, vol. 11, no. 4, pp. 1-14, 2022, doi: 10.3390/foods11040521.
- [14] N. N. Aruwajoye, N. M. D. Buthelezi, A. Mditshwa, S. Z. Tesfay, and L. S. Magwaza, "Assessing the impact of roasting temperatures on biochemical and sensory quality of macadamia nuts (*Macadamia integrifolia*)," *Foods*, vol. 12, no. 11, pp. 1-16, 2023, doi: 10.3390/foods12112116.
- [15] Y. Zhang, L. Dong, J. Zhang, J. Shi, Y. Wang, and S. Wang, "Adverse effects of thermal food processing on the structural, nutritional, and biological properties of proteins," *Annual Review of Food Science and Technology*, vol. 12, pp. 259-286, 2021, doi: 10.1146/annurev-food-062320-012215.
- [16] X. Deng *et al.*, "Insight into the incredible effects of microwave heating: Driving changes in the structure, properties and functions of macromolecular nutrients in novel food," *Frontiers in Nutrition*, 13 October 2022 *Sec. Nutrition and Food Science Technology*, vol. 9, pp. 1-21, 2022, doi: 10.3389/fnut.2022.941527.
- [17] K. Ding, Y. Wang, and D. Luan, "Effects of high-temperature short-time processing on nutrition quality of Pacific saury (*Cololabis saira*) using extracted fatty acids as the indicator," *Food Science and Nutrition*, vol. 11, pp. 157-167, 2022, doi: 10.1002/fsn3.3048.
- [18] G. Giovanelli, G. Aliberti, and E. Casiraghi, "Impact of high-temperature household electric ovens on quality attributes and heat-related by products content of homemade pizzas," *Journal of Food Composition and Analysis*, vol. 133, pp. 1-8, 2024, doi: 10.1016/j.jfca.2024.106460.
- [19] A. E. Akin-Ponnle, "An eco-friendly and low cost iot based room temperature control by fan speed regulation for tropical use," *International Journal of Innovative Science and Research Technology*, vol. 9, no. 8, pp. 622-636, 2024, doi: 10.38124/ijisrt/IJISRT24AUG921.
- [20] S. Ilchev, "Design and development of an electronic controller for accurate temperature management for storage of biological and chemical samples in healthcare," *Computation*, vol. 12, no. 5, pp. 1-19, 2024, doi: 10.3390/computation12050102.
- [21] L. M. Pires, J. Figueiredo, R. Martins, J. Nascimento, and J. Martins, "Design and development of a low-power IoT system for continuous temperature monitoring," *Designs*, vol. 9, no. 3, pp. 1-22, 2025, doi: 10.3390/designs9030073.
- [22] C. S. Domján, M. A. Valente, and M. R. Romero, "Development of a multiple temperature sensors device for the characterization, control and monitoring of microbiological incubators," *Sensors*, vol. 24, pp. 1-18, 2024, doi: 10.3390/s24237671.
- [23] T. Siddiqua, I. Uddin, Md. R. Hasan, and R. Begum, "Effect of heating and Re-heating on physico-chemical properties of rice bran oil and soybean oil," *Journal of Agriculture and Food Research*, vol. 15, pp. 1-10, 2024, doi: 10.1016/j.jafr.2024.100979.
- [24] A. Rabbani, M. Ayyash, C. D. C. D'Costa, G. Chen, Y. Xu, and A. Kamal-Eldin, "Effect of heat pasteurization and sterilization

- on milk safety, composition, sensory properties, and nutritional quality," *Foods*, vol. 14, no. 8, pp. 1-30, 2025, doi: 10.3390/foods14081342.
- [25] S. A. Mehdizadeh, "Machine vision based intelligent oven for baking inspection of cupcake: Design and implementation," *Mechatronics*, vol. 82, pp. 1-10, 2022, doi: 10.1016/j.mechatronics.2022.102746.
- [26] W. Liang, G. Qiang, L. Fan, H. Zhang, Z. Ye, and S. Tang, "Automatic indoor thermal comfort monitoring based on BIM and IoT technology," *Buildings*, vol. 14, no. 11, pp. 1-23, 2024, doi: 10.3390/buildings14113361.
- [27] F. Peprah, S. Gyamfi, M. Amo-Boateng, E. Buadi, and M. Obeng, "Design and construction of smart solar powered egg incubator based on GSM/IoT," *Scientific African*, vol. 17, p. e01326, 2022, doi: 10.1016/j.sciaf.2022.e01326.
- [28] K. Kumar, A. Verma, and P. Verma, "IoT-HGDS: Internet of Things integrated machine learning based hazardous gases detection system for smart kitchen," *Internet of Things*, vol. 28, pp. 1-16, 2024, doi: 10.1016/j.iot.2024.101396.
- [29] N. Mishra, S. K. Jain, N. Agrawal, N. K. Jain, N. Wadhawan, and N. L. Panwar, "Development of drying system by using internet of things for food quality monitoring and controlling," *Energy Nexus*, vol. 11, pp. 1-10, 2023, doi: 10.1016/j.nexus.2023.100219.
- [30] B. Mobaraki, S. Komarizadehasl, F. J. C. Pascual, and J. A. Lozano-Galant, "Application of low-cost sensors for accurate ambient temperature monitoring," *Buildings*, vol. 12, pp. 1-24, 2022, doi: 10.3390/buildings12091411.
- [31] D. Yunita, A. S. Nurazis, J. Juanda, I. S. Nasution, and S. Satriana, "Design and examination of yogurt maker machine with sensor temperature DS18B20," *Lampung Agricultural Engineering Journal*, vol. 13, no. 1, pp. 250-259, 2024, doi: 10.23960/jtep-l.v13i1.250-259.
- [32] M. A. N.-Sanchez, R. Olivera-Reyna, R. Olivera-Reyna, R. J. Perez-Chimal, and J. U. Munoz-Minjares, "IoT-based classroom temperature monitoring and missing data prediction using Raspberry Pi and ESP32," *Journal of Robotics and Control (JRC)*, vol. 6, no. 1, pp. 234-245, 2025, doi: 10.18196/jrc.v6i1.24345.
- [33] R. N. Rohmah, Y. Oktafianto, N. Nurokhim, H. Supriyono, and A. Supardi, "Pest control system on agricultural land using IoT electronic controller," *Journal of Applied Engineering and Technological Science*, vol. 5, no. 2, pp. 1011-1019, 2024, doi: 10.37385/jaets.v5i2.4592.
- [34] K. McDowell, Y. Zhong, K. Webster, H. J. Gonzalez, A. Z. Trimble, and C. Mora, "Comprehensive temperature controller with internet connectivity for plant growth experiments," *HardwareX*, vol. 10, pp. 1-12, 2021, doi: 10.17605/OSF.IO/J7ZKV.
- [35] L. P. Madrigal, J. A. R. Rama, D. A. M. Sánchez, J. L. C. Mustelier, M. A. Sanjuán, and J. L. P. Alfaro, "Cost-effective temperature sensor for monitoring the setting time of concrete," *Applied Sciences*, vol. 14, no. 11, pp. 1-15, 2024, doi: 10.3390/app14114344.
- [36] M. A. Scrugli, B. Blažica, L. Raffo, and P. Meloni, "A Microcontroller-Based Platform for Cognitive Tracking of Sensorimotor Training," *IEEE Access*, vol. 11, pp. 70778-70794, 2023, doi: 10.1109/ACCESS.2023.3294097.
- [37] R. Weiss, M. Diehl, and J. Reuter, "Predictive temperature control of an industrial heating process," *IFAC PapersOnLine*, vol. 58, no. 18, pp. 107-112, 2024, doi: 10.1016/j.ifacol.2024.09.017.
- [38] M. Saad, A. H. Amhedb, and M. A. Sharqawi, "Real time DC motor position control using PID controller in LabVIEW," *Journal of Robotics and Control (JRC)*, vol. 2, no. 5, pp. 342-348, 2021, doi: 10.18196/jrc.25104.
- [39] D. Taler, T. Sobota, M. Jaremkiwicz, and J. Taler, "Influence of the thermometer inertia on the quality of temperature control in a hot liquid tank heated with electric energy," *Energies*, vol. 13, pp. 1-18, 2020, doi: 10.3390/en13154039.
- [40] S. N. Giménez, J. M. H. Durá, F. X. B. Ferragud, and R. S. Fernández, "Design and Experimental Validation of the Temperature Control of a PEMFC Stack by Applying Multiobjective Optimization," *IEEE Access*, vol. 8, pp. 183324-183343, 2020, doi: 10.1109/ACCESS.2020.3029321.
- [41] L. J. Ngalimin, E. T. Christina, and D. Kristyawati, "Lighting system automation using a relay based on radio frequency identification tag input and kiosks' information access with Telegram application in the modern market," *Applied Research and Smart Technology (ARSTech)*, vol. 4, no. 1, pp. 25-32, 2023, doi: 10.23917/arstech.v4i1.1473.
- [42] A. Ulinuha and F. M. Febryan, "Remote Monitoring System of Water Quality for Shrimp Fishery Pond Based on Microcontroller," in *2024 International Conference on Smart Computing, IoT and Machine Learning (SIML)*, Surakarta, Indonesia, 2024, pp. 8-12, doi: 10.1109/SIML61815.2024.10578096.
- [43] N. Fanzury and M. Hwang, "Real-time identification of mixed and partly covered foreign currency using YOLOv11 Object Detection," *AI*, vol. 6, no. 10, pp. 1-21, 2025, doi: 10.3390/ai6100241.
- [44] S. B. Mamun, I. J. Payel, M. T. Ahad, A. S. Atkins, B. Song, and Y. Li, "Grape Guard: A YOLO-based mobile application for detecting grape leaf diseases," *Journal of Electronic Science and Technology*, vol. 23, no. 1, pp. 1-15, 2025, doi: 10.1016/j.jnlest.2025.100300.
- [45] M. C. A. Prabowo, I. Sayekti, S. Astuti, S. T. Nursaputro, and S. Supriyati, "Development of an IoT-based egg incubator with PID control system and mobile application," *JOIV: International Journal Informatics Visualization*, vol. 8, no. 1, pp. 465-472, 2024, doi: 10.62527/joiv.8.1.2044.
- [46] M. Mieszczakowska-Frąć, K. Celejewska, and W. Płocharski, "Impact of innovative technologies on the content of vitamin C and its bioavailability from processed fruit and vegetable products," *Antioxidants*, vol. 10, no. 1, pp. 1-19, 2021, doi: 10.3390/antiox10010054.
- [47] D. P. Guragain, B. Shrestha, and I. Bajracharya, "A low-cost centralized IoT ecosystem for enhancing oyster mushroom cultivation," *Journal of Agriculture and Food Research*, vol. 15, pp. 1-17, 2024, doi: 10.1016/j.jafr.2023.100952.
- [48] A. Zuhaer, A. Khandoker, N. Enayet, P. K. P. Partha, and M. A. Awal, "Sustainable aquaculture: An IoT-integrated system for real-time water quality monitoring featuring advanced DO and ammonia sensors," *Aquacultural Engineering*, vol. 112, pp. 1-12, 2026, doi: 10.1016/j.aquaeng.2025.102620.
- [49] C. A. U. Hassan *et al.*, "Design and implementation of real-time kitchen monitoring and automation system based on Internet of Things," *Energies*, vol. 15, no. 18, pp. 1-16, 2022, doi: 10.3390/en15186778.
- [50] F. Dimmohammadi, A. M. Farook, and M. Shafiee, "Improving energy efficiency in buildings with an IoT-based smart monitoring system," *Energies*, vol. 18, no. 5, pp. 1-29, 2025, doi: 10.3390/en18051269.
- [51] Y. Gao and W. Zhu, "A segmented adaptive PID temperature control method suitable for industrial dispensing system," *Electronics*, vol. 14, no. 11, pp. 1-15, 2025, doi: 10.3390/electronics14112306.
- [52] M. M. Hussein *et al.*, "Modern temperature control of electric furnace in industrial applications based on modified optimization technique," *Energies*, vol. 15, no. 22, pp. 1-12, 2022, doi: 10.3390/en15228474.
- [53] L. Ferrarini, "A predictive reinforcement learning approach for temperature control in buildings," *IFAC PapersOnLine*, vol. 56, no. 2, pp. 11032-11037, 2023, doi: 10.1016/j.ifacol.2023.10.804.
- [54] C. Ates, D. Bicat, R. Yankov, J. Arweiler, R. Koch, and H.-J. Bauer, "Model predictive evolutionary temperature control via neural-network-based digital twins," *Algorithms*, vol. 16, no. 8, pp. 1-26, 2023, doi: 10.3390/a16080387.
- [55] G. Wu, Y. Wang, Q. Gong, L. Li, and X. Wu, "An Intelligent Temperature Control Algorithm of Molecular Beam Epitaxy

- System Based on the Back-Propagation Neural Network,” *IEEE Access*, vol. 10, pp. 9848-9855, 2022, doi: 10.1109/ACCESS.2022.3143811.
- [56] H. Li, G. Lu, J. Su, T. Hou, F. Huang, and Y. Pan, “Improved Particle Swarm Fuzzy PID Temperature Control for the Pellet Grills,” *IEEE Access*, vol. 12, pp. 66373-66381, 2024, doi: 10.1109/ACCESS.2024.3397663.
- [57] O. D. Akolade, O. F. Oziomachuwku, and O. Osemwegie, “Development Of A Portable Incubator For The Detection Of Coliform In Water Using Iot,” in *2023 2nd International Conference on Multidisciplinary Engineering and Applied Science (ICMEAS)*, Abuja, Nigeria, 2023, pp. 1-5, doi: 10.1109/ICMEAS58693.2023.10379367.
- [58] T. Kone, N. G. Anoh, B. G. Yatanan, Y. A. A. Brou, N. J. Ahoutou, and J. D. A. Allou, “Design and development of an IoT-based intelligent incubator,” *Engineering and Technology Journal*, vol. 09, no. 1, pp. 3396-3401, 2024, doi: 10.47191/etj/v9i01.21.
- [59] R. Cuervo, M. A. Rodríguez-Lázaro, R. Farré, D. Gozal, G. Solana, and J. Otero, “Low-cost and open-source neonatal incubator operated by an Arduino microcontroller,” *HardwareX*, vol. 15, pp. 1-14, 2023, doi: 10.1016/j.ohx.2023.e00457.
- [60] M. Islamiyah and S. Arifin, “Smart fuzzy incubator for free-range chicken on internet of things,” *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 14, no. 5, pp. 5344-5355, 2024, doi: 10.11591/ijece.v14i5.pp5344-5355.

BIOGRAPHIES OF AUTHORS



Heru Supriyono    is a full time lecturer at Department of Electrical Engineering Universitas Muhammadiyah Surakarta, Indonesia. His research interests include development of computer system-related applications for broad areas of instrumentation, measurement, monitoring, and control. He can be contacted at email: Heru.Supriyono@ums.ac.id.



Agus Supardi    is a full time lecturer at Department of Electrical Engineering Universitas Muhammadiyah Surakarta, Indonesia. His research interests are in electrical system design including in electrical motor application, energy management, and power generating. He can be contacted at email: Agus.Supardi@ums.ac.id.



Pramudya Kurnia    is a full time lecturer at Department of Nutritional Science Universitas Muhammadiyah Surakarta, Indonesia. His research interests are in food processing, food storing, and nutritional related food materials. He can be contacted at email: Pramudya.Kurnia@ums.ac.id.



Mohammad Dwiki Aji Nugroho    is a full time undergraduate student at Department of Electrical Engineering Universitas Muhammadiyah Surakarta, Indonesia. His interests are in the embedded systems and robotics. He can be contacted at email: D400210054@student.ums.ac.id.



Muhammad Satria Ananta    is a full time undergraduate student at Department of Electrical Engineering Universitas Muhammadiyah Surakarta, Indonesia. His interests are in the embedded systems and robotics. He can be contacted at email: D400210051@student.ums.ac.id.



Helmi Hidayatullah    is a full time undergraduate student at Department of Electrical Engineering Universitas Muhammadiyah Surakarta, Indonesia. His interests are in the embedded systems and robotics. He can be contacted at email: D400210102@student.ums.ac.id.